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# IMPACT OF SLUM UPGRADING TO RIVER WATER QUALITY IN YOGYAKARTA CITY, INDONESIA

## *DAMPAK PERBAIKAN KAWASAN KUMUH TERHADAP KUALITAS AIR SUNGAI DI KOTA YOGYAKARTA, INDONESIA*

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## ABSTRACT

Air limbah domestik dari area kumuh menjadi salah satu penyebab pencemaran air sungai akibat dari kurangnya akses sanitasi. Di Kota Yogyakarta, area kumuh berada pada bantaran sungai Winongo, Code dan Gajahwong. Adanya perbaikan kawasan kumuh telah mengurangi luasannya dari 264.5 ha menjadi 114.72 ha dari 2016 ke 2020. Penelitian ini bertujuan untuk menghitung korelasi antara perbaikan kawasan kumuh dengan kualitas air sungai. Penelitian ini menggunakan 10 parameter kualitas air sungai dari tahun 2013 sampai 2021 diperoleh dari Pemerintah Kota Yogyakarta. Melalui uji *Pearson Correlation Coefficient* and *Spearman Rank,* ditemukan bahwa kepadatan penduduk mempunyai korelasi positif dengan *Total Coliform* dan *Fecal Coliform* ($p<0.05$). Rasio kawasan kumuh juga menunjukkan korelasi positif dengan BOD, COD, TSS, pH dan $NH_3$-N ($p<0.05$). Jumlah Instalasi Pengolahan Air Limbah mempunyai korelasi positif dengan $PO_4$-P ($p= 0.037$) dan jumlah sambungan rumah tangga ke instalasi pengolahan air limbah juga mempunyai korelasi positif dengan $P0_4$-P ($p=0.028$). Melalui uji *Paired t-test* dan *Wilcoxon Signed-Rank test,* terjadi penurunan yang signifikan pada BOD, COD, $NH_3$-N, pH, dan TSS ($p<0.05$). Penelitian ini menyimpulkan bahwa perbaikan area kumuh telah menurunkan pencemar organik dan padatan terlarut, meskipun instalasi pengolahan air limbah tidak bekerja secara maksimal untuk menurunkan parameter $PO_4$-P and Coliform, sehingga perlu ditingkatkan kinerjanya. Penelitian ini dapat menjadi masukan dalam peningkatan manajemen sungai dan perkotaan di kota Yogyakarta.

***Keywords:*** *Pencemaran Sungai; Kualitas Air Sungai; Perbaikan Area Kumuh; Perencanaan Perkotaan; Air Limbah.*

## ABSTRACT

Due to a lack of proper sanitation services, the disposal of residential wastewater from slum areas has become one of the river pollution contributors. In Yogyakarta slums were concentrated along the riverbanks of the Winongo, Code and Gajahwong rivers. Due to slum upgrading, slums have declined from 264.5 ha to 114.72 ha between 2016 and 2020. This research aims to determine the correlation between slum upgrading and river water quality. The data was acquired from the Government of Yogyakarta City, Indonesia, and examined using ten water parameters from 2013 to 2021. Using Pearson

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Correlation Coefficient and Spearman Rank, it was found that population density positively correlated with Total Coliform and Fecal Coliform ($p<0.05$). It was also seen that the slum ratio showed a positive correlation with BOD, COD, TSS, pH, and $NH_3$-N ($p<0.05$). The number of WWTP had a positive correlation with $PO_4$-P (p= 0.037), whereas the number of connected houses to WWTP reported a positive correlation with $P0_4$-P (p=0.028). In addition, a significant decrease in BOD, COD, NH3-N, pH, and TSS were found using the Paired t-test and the Wilcoxon Signed-Rank test. ($p<0.05$). Slum upgrading notably reduced organic pollutants and suspended solids. However, the performance of WWTP did not perform a maximal contribution to reducing $PO_4$-P and Coliform; therefore, it is necessary to improve the performance. This study might be used to enhance the river and urban management in Yogyakarta City.

***Keywords:*** *River Pollution; River Water Quality; Slum Upgrading; Urban Planning; Wastewater.*

## INTRODUCTION

The UN estimates that by 2025, 68% of people will reside in urban areas, up from 52% in 2012 [1]. Urbanization has harmed river water quality due to untreated industrial and domestic sewage [2]. Water pollution is a recent issue faced by many societies in the world. Water contamination arises from point and nonpoint sources [3], for example, urban runoff [4], agricultural [5], household sewage, and wastewater treatment plant (WWTP) as a sanitation infrastructure [6] [7], and industrial activities [8]. Domestic wastewater has become the largest pollutant source in urban areas in Indonesia, with only around 5% of sewage being safely disposed of while the rest was released into surface and groundwater [1]. The number of individuals connected to the sewage system has rapidly expanded since it was previously managed in septic tanks, resulting in nitrogen (N) and phosphorus (P) contamination. [9]. In addition, fecal and total Coliform has threatened river pollution [10] and public health [1].

In addition, the rapid rate of urbanization in Indonesia also increases the number of slum areas in major cities. A shortage of sanitary facilities and infrastructure, including safe water, sewage, drainage, and waste disposal, is a common problem in slum areas [11]. Slum upgrading was thought to be more successful in tackling slums than relocating slum dwellers, which can often generate more problems than it solves [12]. Slum upgrading includes physical upgrading consisting of organizing street networks and settlements: building public service systems, and providing open space and facilities exposing the place's physical beauty [13]. Due to a lack of waste infrastructure, the main issue with riverbank typologies is a lack of wastewater management [14]. In Yogyakarta, slums mainly were concentrated around three major rivers, and there was a relationship between slums and disaster-prone areas [15].

Land use and the water quality of adjacent aquatic systems within a watershed are widely related [16]. The correlation between land-use patterns and river water quality has been widely studied [17][18][19] [20] and assessed the river water quality using a water quality index [21] [22]. Yogyakarta City's water quality index (WQI), issued by the Yogyakarta City Environmental Agency, showed a declining trend—meaning it became worse—from 41.98 in 2019 [23] to 38.44 in 2021 [24]. It indicates that the river's health has deteriorated and has become one of the strategic issues to address in city planning. However, Yogyakarta's slum area declined from 264.9 hectares in 2016 to 114.7 ha in 2020, along with WWTP's development may possibly minimize environmental pollution in rivers. Slum upgrading might theoretically improve river water quality. However, there is yet a scarcity of research on the relationship between slums and river water quality. Slum residents may impact their environment due to a lack of basic facilities, resulting in contaminated soil, polluted air, and polluted streams [25] and presenting a severe challenge to urban development and planning [26].

This study aimed to identify the correlation between river water quality response to slum upgrading in Yogyakarta City, Indonesia. Statistical analysis was utilized to analyze the correlation between water quality parameters and variables related to the slum upgrading: population density, slum ratio in the basin, number of WWTP, and the number of connected houses to WWTP. The pairwise test was used to find the different river water quality parameters before and after slum upgrading. This research might enhance river and wastewater management in slum areas.

## METHODS

### Study Area

This research was conducted in Yogyakarta City, Indonesia. It covers 32.5 Km² and is divided into 14 Districts and 45 Sub Districts. It was inhabited by 376,324 people with an average density of 11,579 people/Km² [27]. The population growth rate constitutes -0.38 in the last decade. Yogyakarta is located between 110° 24’19”to 110° 28’ 53” longitude and 7°49’26” to 7°15’24” latitude. The distance from north to south is approximately 7.5 kilometers, while the distance from west to east is about 5.6 kilometers.

Yogyakarta is a lowland city with typical monsoon rainfall with two seasons: rainy and dry season. The average annual rainfall intensity is around 2000 mm [27]. The average humidity is relatively high, the highest in January and March (88%) and the lowest in September (77%). The average air pressure is 995.61 millibars, and the average air temperature is 26.26 °C. The topography of Yogyakarta City is relatively flat, with an elevation of 75-132m of mean sea level. Almost 88.94% of the Yogyakarta City area is 0-2°. Furthermore, 9.64% are on a 2-15°, and 1.09% are on a slope of 15-40°. The remaining 0.34% are on a slope above 40°, mainly located on riverbanks.

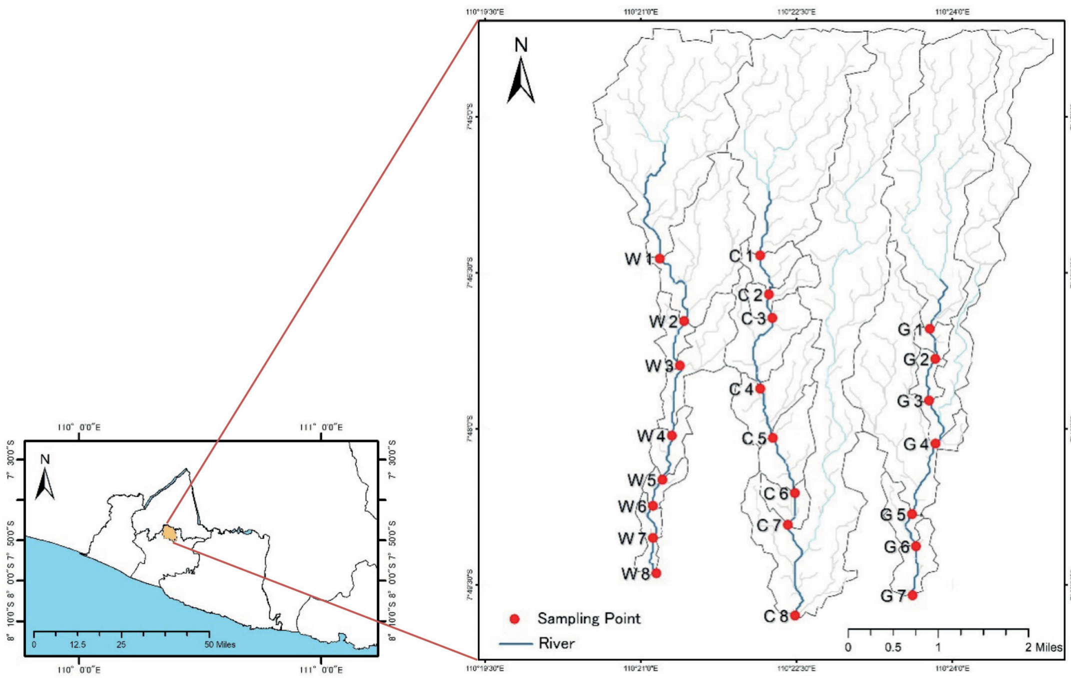


**Figure 1.**
River Water Quality Monitoring Point in Yogyakarta City
(W: Winongo, C: Code, G: Gajahwong)
Source: Author Analysis (2022)

Three river passes through the city from the north to the south. The rivers are the Winongo River in western Yogyakarta City. The Code River is in the middle, and the Gajahwong River flows on the eastern side. The rivers stretch upstream at Mount Merapi (Special Region of Yogyakarta Province and Central Java Province), Indonesia. Its downstream is in Bantul Regency, finally discharging into the Southern-Java Sea. Figure 1 shows that there are 23 monitoring points from 2013 to 2021. Winongo (W) and Code (C) River has eight monitoring points, while Gajahwong (G) has seven monitoring points. The parameters of the river's water quality were acquired from the monitoring points.

## Data and Materials

Initially, the water quality data were obtained from the water quality report by the Environment Agency of Yogyakarta City from 2013 to 2021. There were ten parameters used in the analysis. Not all data was obtained in the 2013-2021 period. For example, Fecal and Total Coliform and $PO_4$-P data were only available in 2019-2021.

Digital Elevation Model (DEM) was used to calculate and delineate the river basin. This processing used SRTM30 obtained from https://earthdata.nasa.gov/ with a spatial resolution of 30 m. The basin delineation used ArcGIS 10.4.1 to utilize hydrological tools, including flow direction and accumulation [28]few studies have investigated the simultaneous effects of macro-scale parameters (MSPs.

a. *Population Density*
   The population density was calculated by dividing the total population in a sub-basin by the sub-basin area. The population data was then divided into two data periods. The first period's data was the average population from 2013 to 2016, while the second period's data was the average population from 2019 to 2021. The highest population density is seen in the Winongo River basin at W5 and W6 (Fig.2). Likewise, there is no substantial change in population density between the two data periods, except for a slight shift in G3 and G4.

b. *Slums*
   The first slum status was formed in 2016, according to the Mayor of Yogyakarta City's Decision No. 216 of 2016, addressing the establishment of slum regions in Yogyakarta City. According to this regulation, Yogyakarta City has approximately 264.9 hectares of slums. Eventually, the Mayor of Yogyakarta City issued Decree No. 158 of 2021 on slums in 2020. It was noted that the number of slums decreased to 114.7 ha. Figure 3 presents the slum status in both periods.

c. *Number of WWTP and Connected Houses to WWTP*
   This variable shows the number of WWTP and the number of connected houses to WWTP in the sub-basins (Figure 4). The WWTP was built on the riverbanks to reduce environmental pollution from domestic wastewater. In Yogyakarta, there are three types of WWTP: on-site WWTP (commonly using a septic tank), which served 1–5 households; community-based, which served 50–150 families; and off-site, which served more than 500 households [29] treatment and recovery systems. Therefore a technical and financial feasibility analysis of these systems was performed using Indonesia as an example. COD, BOD, nitrogen, phosphorus and pathogen removal efficiencies, energy requirements, sludge production, land use and resource recovery potential (phosphorus, energy, duckweed, compost, water. In Period 1, we assumed that WWTP built between the early 2000s and 2016 would be used as initial data. The earlier WWTPs were built before slum upgrading. In addition, the number of connections explicitly represents the number of houses connected to WWTP. The designs were primarily anaerobic systems. During the slum upgrading project between periods 1 and 2, a new WWTP was constructed almost identically to the old anaerobic design.

## Analytical Methods

This research presented rainy seasons from December to February, while dry seasons were from June to August. The river water characteristics were employed at 23 sampling points throughout three rivers in Yogyakarta. These sampling stations have been sorted in ascending order from upstream to downstream (Figure 1).

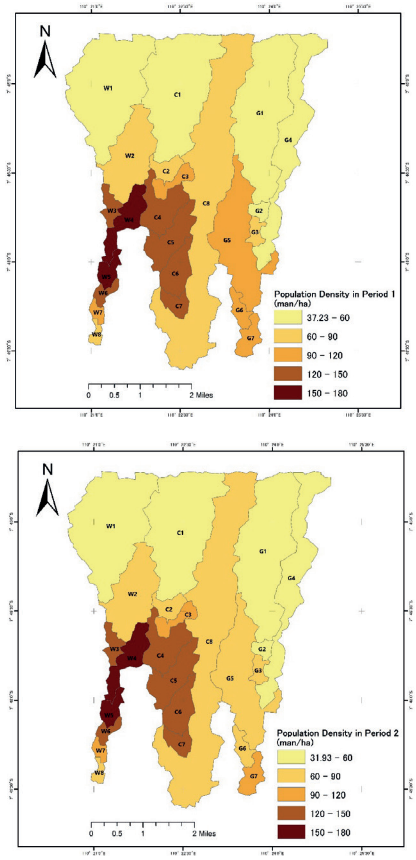


**Figure 2.**
The Population Density in Each Sub-Basin
Source: Author Analysis (2022)

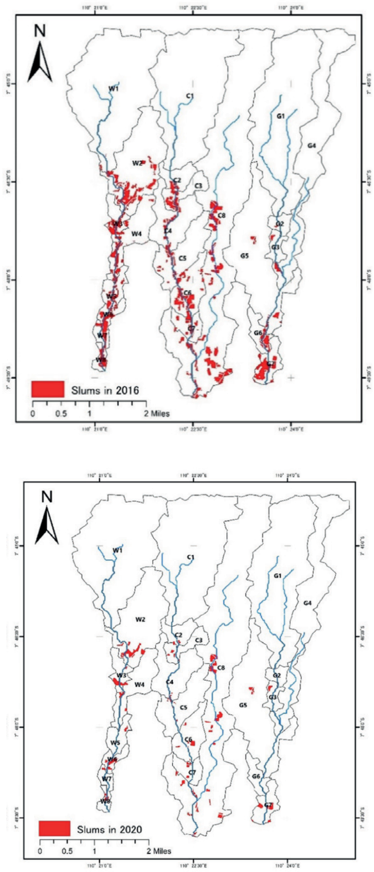


**Figure 3.**
Slums in Each Sub-Basin in Yogyakarta City, Indonesia
Source: Author Analysis (2022)

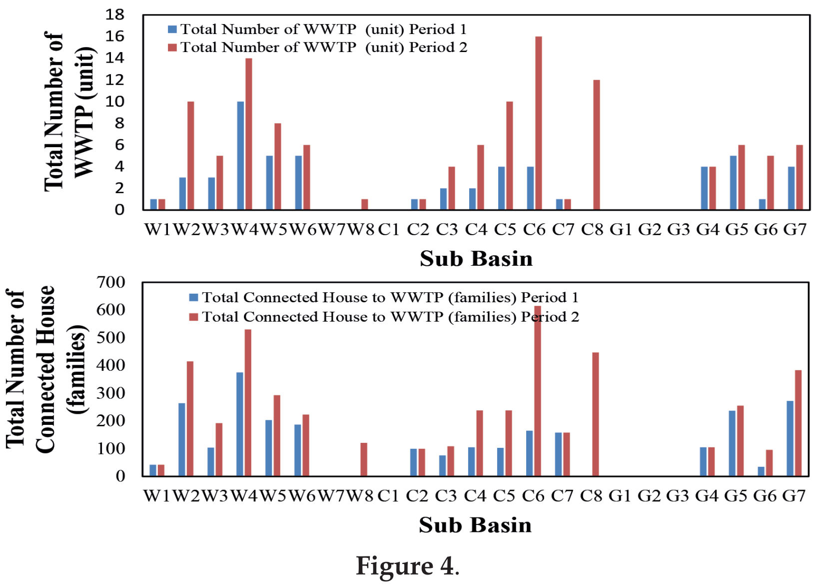


**Figure 4.**
Number Of WWTP and Connected House to WWTP In Each Sub-Basin Winongo (W), Code (C), Gajahwong (G)
Source: Author Analysis (2022)

Watersheds were defined using the ArcGIS 10.4.1 Hydrological tools. Stream models in the river basin were created using flow direction and accumulation. Then, by using weighting, it was found seven classes of streamline. In this research, the authors used a scale of 4-7 to present the streams model. Afterwards, a snap pour-point tool was used to deliver the sampling point in each river basin. As an outlet, it produced small basins or watersheds on each station. From the processing results in ArcGIS 10.4.1, it was found that there are three sub-river basins in the Yogyakarta City area. The three sub-river basins follow the river pattern: the Winongo, Code, and Gajahwong rivers.

Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), pH, Ammonium Nitrogen ($NH_3$-N), Nitrite Nitrogen ($NO_2$-N), and Nitrate Nitrogen ($NO_3$-N) parameters were tested using data from two sets of periods. In this research, we converted the value of Ammonium, Nitrite, and Nitrate from original data into nitrogen forms. Similarly, $PO_4$ was also converted into $PO_4$-P (Phosphate Phosphorus). The Phosphate Phosphorus, Fecal Coliform, and Total Coliform were only tested using data from the second period since these parameters were not measured in the first period (Table 1).

**Table 1**

The Average Value of River Water Quality Parameters in Two Periods (2016 and 2020)

| Parameters | Standard *) | Winongo | | Code | | Gajahwong | |
|---|---|---|---|---|---|---|---|
| | | Period 1 | Period 2 | Period 1 | Period 2 | Period 1 | Period 2 |
| | | Mean | Mean | Mean | Mean | Mean | Mean |
| BOD (mg/l) | 3 | 8.54 | 2.89 | 7.75 | 3.44 | 7.66 | 2.93 |
| COD (mg/l) | 25 | 45.86 | 22.77 | 37.79 | 24.07 | 26.5 | 21.97 |
| TSS (mg/l) | 50 | 94.38 | 8.73 | 110.34 | 10.83 | 112.09 | 8.48 |
| pH | 6-8.5 | 7.36 | 6.86 | 7.5 | 6.88 | 7.28 | 6.84 |
| $NO_2$ (mg/l) | 0.06 | 0.28 | 0.21 | 0.42 | 0.43 | 0.49 | 0.33 |
| $NO_3$ (mg/l) | 10 | 5.77 | 10.14 | 4.96 | 9.52 | 7.78 | 14.2 |
| $NH_3$ (mg/l) | - | 0.43 | 0.11 | 0.34 | 0.17 | 0.59 | 0.11 |
| FC (MPN/100ml) | 1000 | - | 1,156,689 | - | 2,150,765 | - | 1,088,483 |
| TC (MPN/100ml) | 5000 | - | 1,824,755 | - | 3,467,595 | - | 1,970,422 |
| $PO_4$ (mg/l) | 0.2 | - | 0.66 | - | 0.79 | - | 0.8 |

Source: Data Analysis (2022)

*) Provincial Governor's Regulations, Special Region of Yogyakarta No. 20 of 2008, about River Water Quality Standards for Rivers Class 2.

Statistical analysis was utilized to obtain the correlation and the difference in river water quality. The correlation between river water quality indicators and slum variables (slum ratio areas, population density, the number of WWTP, and the number of connected houses to WWTP) was determined using a correlation test. The *Pearson correlation test* is a parametric test used to detect the correlation between variables. It is commonly applied to normally distributed data. Meanwhile, *Spearman Rank Correlation* is a non-parametric test for non-normally distributed data. The significance of changes in river water quality before and after the slum upgrading project was determined using a paired test, *Paired t-test* and *Wilcoxon Signed-Rank Test*. Data were divided into two categories: the initial condition or the first period used data from 2013 to 2016, and the second period used data from 2019 to 2021. This research used Microsoft Excel and IBM SPSS Statistic 25 for Statistical Analysis.

## RESULT AND DISCUSSION

### Correlation Test

The correlation coefficient indicates whether the correlation is positive or negative. A correlation nearing -1 or 1 indicates that the variables are strongly correlated. The *p-value* indicates a correlation among variables. A *p-value* of more than 0.05 suggests an inconsequential correlation, whereas A *p-value* of less than 0.05 shows a substantial correlation.

A correlation test was performed to evaluate the correlation of each independent variable (population density, slum ratio, number of WWTP, and the number of connected houses) to the dependent variables (ten river water parameters). The dry season was considered for the analysis since high-water discharge and velocity will alter pollution dispersal during the rainy season. Pollutants decompose during the dilution process, making it difficult to conclude. The dry season explained the correlation between variables in this correlation test.

Table 2 presents the correlation test between variables. The population density has a 0.437 correlation value with Ammonium Nitrogen (*p-value* 0.011). In addition, Fecal Coliform, and Total Coliform has strong correlation with the population density at correlation coefficient of 0.729 (*p-value* 0.001) and 0.606 (*p-value* 0.013), respectively. It may be inferred that the higher the population density, the higher the Ammonium Nitrogen, Fecal Coliform, and Total Coliform levels. Ammonium Nitrogen is related to domestic wastewater from residents. Along with Fecal and Total Coliform, the number and design of WWTP in a dense population were probably insufficient to treat Ammonium Nitrogen and Coliform properly.

According to field observations, the WWTP may only cover residents with accessible sewage connections. Meanwhile, the alternative for the house, which could not be linked to sewerage, was to create an onsite treatment system or utilize a septic tank. However, the results reveal that the coliform levels in the three rivers were high, implying that the WWTP's design was unable to treat Coliform. The Coliform also shows a high value during the rainy season.

The slum ratio and water quality measures were investigated for correlation. The calculation results show that the slum ratio has a positive correlation with BOD during the dry season with correlation coefficient 0.577 (*p-value* 0.000), COD at correlation coefficient 0.705 (*p-value* 0.000), TSS at correlation coefficient 0.550 (*p-value* 0.001), pH at correlation coefficient 0.515 (*p-value* 0.002), Ammonium Nitrogen at correlation coefficient 0.684 (*p-value* 0.000) and has a -0.619-correlation value with Nitrate Nitrogen (*p-value* 0.000).

The positive correlation indicates that as the slum area shrinks, the BOD, COD, TSS, and Ammonium Nitrogen levels will be. The lowering in the value of this water quality parameter was most likely caused by development during slum upgrading, which also influenced the reduction of these pollutant values. Improvements in WWTP, drainage channels, and construction of banks likely contributed to the decline in BOD, COD, TSS, and Ammonium Nitrogen values. The design of a WWTP with an anaerobic system effectively lowered BOD, COD, and suspended solid values. WWTP in riparian Yogyakarta City used anaerobic systems to be more practical and accessible. Additionally, the embankment's construction may probably have reduced the erosion rate, lowering the TSS value in the second period.

**Table 2**
Result of Correlation Test

| Parameter | Population Density | | | Slum Ratio | | | Number of WWTP | | | Number of Connected House | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Correlation Coefficient | *p-value* | Method | Correlation Coefficient | *p-value* | Method | Correlation Coefficient | *p-value* | Method | Correlation Coefficient | *p-value* | Method |
| BOD (mg/l) | 0.240 | 0.179 | Spearman | .577** | 0.000 | Spearman | -0.017 | 0.926 | Spearman | 0.030 | 0.868 | *Spearman* |
| COD (mg/l) | 0.295 | 0.095 | Spearman | .705** | 0.000 | Spearman | 0.077 | 0.668 | Spearman | 0.120 | 0.506 | *Spearman* |
| TSS (mg/l) | 0.181 | 0.313 | Spearman | .550** | 0.001 | Spearman | -0.202 | 0.261 | Spearman | -0.180 | 0.317 | *Spearman* |
| pH | 0.100 | 0.580 | Pearson | .515** | 0.002 | Spearman | -0.133 | 0.461 | Spearman | -0.165 | 0.360 | *Spearman* |
| $NO_2$-N (mg/l) | 0.237 | 0.184 | Pearson | 0.028 | 0.876 | Spearman | 0.243 | 0.174 | Spearman | 0.249 | 0.161 | *Spearman* |
| $NO_3$-N (mg/l) | -0.235 | 0.188 | Spearman | -.619** | 0.000 | Spearman | 0.112 | 0.534 | Spearman | 0.072 | 0.691 | *Spearman* |
| $NH_3$-N (mg/l) | 0.437* | 0.011 | Pearson | .684** | 0.000 | Spearman | 0.133 | 0.459 | Spearman | 0.137 | 0.446 | *Spearman* |
| Fecal coliform (MPN/100ml) | .729** | 0.001 | Spearman | 0.414 | 0.111 | Spearman | 0.252 | 0.346 | Spearman | 0.281 | 0.291 | *Spearman* |
| Total coliform (MPN/100ml) | .606* | 0.013 | Spearman | 0.267 | 0.318 | Spearman | 0.122 | 0.653 | Spearman | 0.113 | 0.678 | *Spearman* |
| $PO_4$-P (mg/l) | 0.424 | 0.102 | Pearson | 0.273 | 0.307 | Spearman | .526* | 0.037 | Pearson | .549* | 0.028 | Pearson |

Source: Data Analysis (2022)

**. Correlation is significant at the 0.01 level (2tailed).
*. Correlation is significant at the 0.05 level (2tailed).

The correlation test reveals that the number of WWTP solely correlated with the $PO_4$-P variable in the dry season. It correlates positively with a correlation value of 0.526 (*p-value* 0.037) and is more significant in the dry season than in the rainy season (Figure 5).

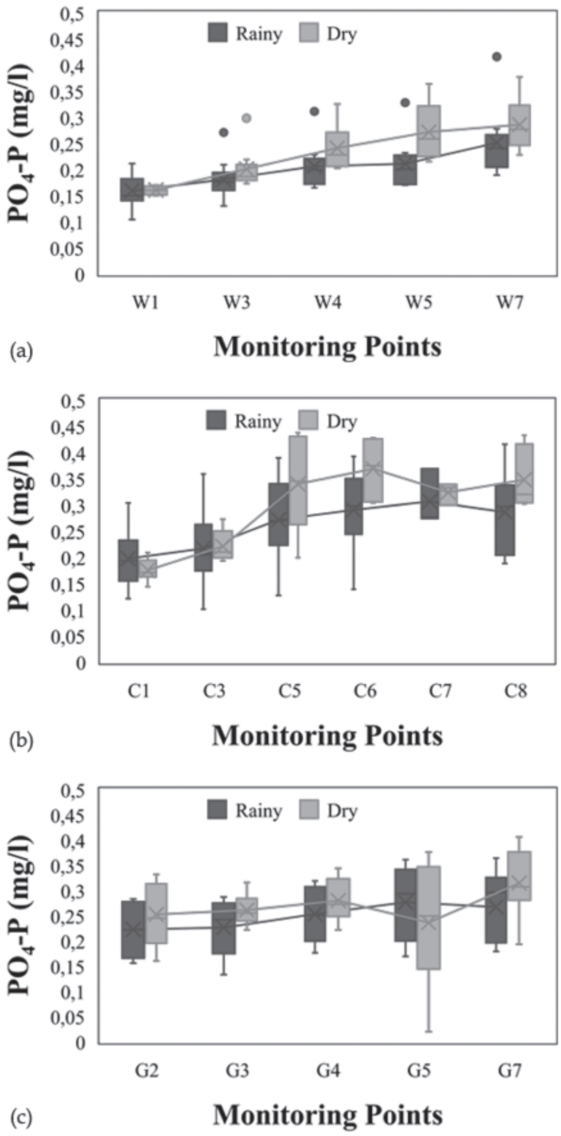


**Figure 5.**
Spatial Distribution of $PO_4$-P in (a) Winongo, (b) Code and (c) Gajahwong
Source: Author Analysis (2022)

Even though several new WWTPs have been constructed, the WWTP appeared unable to handle $PO_4$-P appropriately. Figure 5 depicts the gradual increase of $PO_4$-P in the three rivers from upstream to downstream, indicating an accumulation of $PO_4$-P. $PO_4$-P was most likely produced by household sewage. Besides nitrogen, $PO_4$-P may contribute to eutrophication, causing algae blooms in rivers.

During the dry season, river water quality data was used to conduct a correlation test on the number of connected houses. Also, a correlation value of 0.549 indicated a positive correlation to $PO_4$-P (*p-value* 0.028). A positive correlation was reported between the number of connected houses. It is suggested that it is most likely due to the design of the WWTP being insufficient to handle $PO_4$-P.

## Pairwise test

The difference in river-water-quality parameters between the first and second periods was determined using pairwise tests to measure the significance of differences between the two pairs of samples. It was used in this research to investigate if slum upgrading significantly influenced changes in river water quality in Yogyakarta. The *Wilcoxon Signed-Rank Test* was used for data that were not normally distributed, whereas *the paired t-tests* were utilized for normally distributed data. The *p-value* shows if the difference between the two samples is statistically significant. A *p-value* more than 0.05 indicates that the difference is insignificant, whereas a *p-value* less than 0.05 indicates that the difference is significant. The difference in the values of the two criteria was immediately shown using data on river water quality during the dry season. Meanwhile, the river water quality parameters included BOD, COD, Ammonium Nitrogen, Nitrite Nitrogen, Nitrate Nitrogen, pH, TDS, and TSS. Other parameters, e.g., Phosphate Phosphorus, Fecal, and Total Coliform, were omitted since no data was obtained in period 1 (2016).

**Table 3**
Result of Pairwise Test

| Parameter | Dry Season | | |
|---|---|---|---|
| | *p-value* | Method | Status |
| BOD (mg/l) | 0.007 | *Wilcoxon Signed-Rank Test* | Decrease |
| COD (mg/l) | 0.016 | *Paired t-test* | Decrease |
| TSS (mg/l) | 0.005 | *Wilcoxon Signed-Rank Test* | Decrease |
| pH | 0.000 | *Paired t-test* | Decrease |
| $NH_3$-N (mg/l) | 0.044 | *Wilcoxon Signed-Rank Test* | Decrease |
| $NO_2$-N (mg/l) | 0.766 | *Wilcoxon Signed-Rank Test* | - |
| $NO_3$-N (mg/l) | 0.005 | *Wilcoxon Signed-Rank Test* | Increase |

Source: Data Analysis (2022)

The result in table 3 shows some parameters declined while only Nitrate Nitrogen increased. The decline in BOD, COD, Ammonium Nitrogen and TSS parameters corresponded to the results of the correlation analysis, indicating that the decrease in these parameters is linked to the slum ratio. The rapid oxidation rate of Ammonium Nitrogen to Nitrate Nitrogen is most likely responsible for the rise in Nitrate Nitrogen. Elevated Nitrate Nitrogen levels in groundwater most likely drive the presence of high Nitrate Nitrogen levels in the surface water. Due to low water quality standards, especially drinking water, high Nitrate Nitrogen levels can be detrimental to human health and cause diseases that affect children (Baby Blue syndrome).

## DISCUSSION

As seen in Figure 2, there was no substantial shift in population density between sub-basins, indicating that slum upgrading was preferred to relocation. However, it still left issues where the coliform value is excessive and exceeds the standard value of river water parameters. The correlation between population density and pathogenic parameters is likely due to groundwater pollution caused by unsafe septic tanks not positioned reasonably far from wells as water sources [30]both in the urban and as well as in the rural area due to its quantity and quality advantages. The rapid population growth has caused an increase of groundwater demand, consequently it is facing some problems to the sustainability of groundwater supply. Lowering of groundwater level has been observed in some places, as well as the degradation of groundwater quality. Earthquake which stroke Yogyakarta on 27 May 2006, damaged buildings and other infrastructures in the area, including roads and bridges. It might also damage the underground structures such as septic tanks, and pipes underneath the earth surface. It might cause cracking of the geologic structures. Furthermore, the damage of underneath infrastructures might create groundwater quality changes in the area. Some complains of local community on lowering and increasing groundwater level and groundwater quality changes were noted. Field observation and investigation were conducted, including collection of groundwater samples close to (the. Septic tank leaks were likely to pollute groundwater [31][32], which may lead to polluting rivers. When the water flow increases during the rainy season, it likely pushes groundwater through the aquifer layer and to the water surface, causing Fecal Coliform and Total Coliform levels to rise. Another possibility is that the WWTP did not perform optimally, particularly in densely populated areas.

The provision of wastewater treatment facilities in highly populated areas must necessarily consider the load, design, and maintenance. The WWTP was designed as an anaerobic system (septic tank and anaerobic baffled reactor-anaerobic filters) more suitable for reducing organic pollutants and suspended solids. An anaerobic baffled reactors-anaerobic filters feature relatively affordable operational and maintenance expenses, and it was influential in reducing organic pollutants and suspended solids, even though the effectiveness of this system is still lacking in treating nutrients and pathogens [33]

According to the correlation test, the slum ratio was positively correlated with BOD, COD, TSS, and Ammonium Nitrogen and solely inversely correlated with Nitrate Nitrogen. The positive correlation implies that some physical improvements, such as the building of a WWTP and the development of the drainage network, and embankment, are closely correlated to these parameters. The WWTP design could be related to decreased BOD, COD, and TSS parameters. In principle, the WWTP design lowers the value of these parameters. Furthermore, riverbank embankment construction most likely lowered the rate of soil erosion as well.

On the other hand, the Nitrate Nitrogen parameter is inversely related to the slum ratio. The pairwise test also revealed that only the Nitrate Nitrogen parameter increased. The high Nitrate Nitrogen value is most likely due to the rapid oxidation of ammonium Nitrogen to Nitrate Nitrogen. Due to a lack of Total Nitrogen (TN) in the data source, the nitrogen cycle cannot be addressed further. However, another research found significant nitrate levels in well water in the Code River's midstream [34], indicating the high Nitrate in groundwater affects river water quality. Notably, high Nitrate is a toxic parameter in water, causing health problems in humans [35][36][37]the grey water footprint (GWF.

The correlation test on the number of WWTP and the number of the connected houses with river water quality parameters demonstrates only a correlation between $PO_4$-P and the number of the connected house. The likely cause is an increase in the connection of inhabitants' wastewater channeled to WWTP [38] makes these parameters accumulate in WWTP. Figure 5 also depicts that $PO_4$-P increases from upstream to downstream gradually. Furthermore, the low efficiency in $PO_4$-P removal caused the $PO_4$-P value to accumulate in the WWTP.

## CONCLUSION

Slum upgrading likely has improved river water quality since BOD, COD, and TSS levels have decreased. However, the WWTP design considered was unlikely to remove Coliform and $PO_4$-P. Untreated sewage by unsafe septic tanks most likely produced the bacterial parameters, resulting in groundwater and surface water pollution. Moreover, Ammonium Nitrogen was thought to be decreasing, and the increase in Nitrate Nitrogen should be highlighted. It was most likely caused by groundwater pollution in each sub-basin or the high oxidation rate in the aquatic environment. This study suggests that the subsequent research could investigate the WWTP performance in the field.

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## BIBLIOGRAPHY

[1] A. D. Bank, *ASIAN DEVELOPMENT BANK INDONESIA Country Water assessment Indonesia Country Water assessment*. 2016.

[2] M. Kumar, M. Sharif, and S. Ahmed, "Impact of urbanization on the river Yamuna basin," *Int. J. River Basin Manag.*, 2020, doi: 10.1080/15715124.2019.1613412.

[3] K. M. Vigil, *Clean Water: An Introduction to Water Quality and Water Pollution*, Second Edi. Corvallis: Oregon State University Press, 1996.

[4] A. Müller, H. Österlund, J. Marsalek, and M. Viklander, "The pollution conveyed by urban runoff: A review of sources," *Science of the Total Environment*. 2020, doi: 10.1016/j.scitotenv.2019.136125.

[5] B. Wang, "Agricultural economy loss in Yangtze River basin in China caused by water-environment pollution," *Nat. Environ. Pollut. Technol.*, 2016.

[6] A. Al-Omari, I. Farhan, T. Kandakji, and F. Jibril, "Zarqa River pollution: impact on its quality," *Environmental Monitoring and Assessment*. 2019, doi: 10.1007/s10661-019-7283-9.

[7] B. K. Mishra, R. K. Regmi, Y. Masago, K. Fukushi, P. Kumar, and C. Saraswat, "Assessment of Bagmati river pollution in Kathmandu Valley: Scenario-based modeling and analysis for sustainable urban development," *Sustain. Water Qual. Ecol.*, 2017, doi: 10.1016/j.swaqe.2017.06.001.

[8] R. Afroz, M. M. Masud, R. Akhtar, and J. B. Duasa, "Water pollution: Challenges and future direction for water resource management policies in malaysia," *Environ. Urban. ASIA*, 2014, doi: 10.1177/0975425314521544.

[9] D. Suwarno, A. Löhr, C. Kroeze, and B. Widianarko, "Fast increases in urban sewage inputs to rivers of Indonesia," *Environ. Dev. Sustain.*, 2014, doi: 10.1007/s10668-014-9514-0.

[10] E. Novita, H. A. Pradana, B. H. Purnomo, and A. I. Puspitasari, "River water quality assessment in East Java, Indonesia," *J. Water L. Dev.*, 2020, doi: 10.24425/jwld.2020.135040.

[11] L. P. Defi, I. Kusumayanti, W. M. Fatimah, P. W. Sarli, and P. Soewondo, "THE RISE OF RAINBOW VILLAGE: OPTIMIZING AESTHETICAL PROGRAM TO ACCELERATE SANITATION ACCESS," *Int. J. GEOMATE*, 2022, doi: 10.21660/2022.90.7569.

[12] J. Abbott, "An analysis of informal settlement upgrading and critique of existing methodological approaches," *Habitat Int.*, 2002, doi: 10.1016/S0197-3975(01)00049-2.

[13] M. V. Michiani and J. Asano, "Physical upgrading plan for slum riverside settlement in traditional area: A case study in Kuin Utara, Banjarmasin, Indonesia," *Front. Archit. Res.*, 2019, doi: 10.1016/j.foar.2019.03.005.

[14] E. F. Rini, P. Rahayu, and G. K. Sinniah, "Sustainable river management: Land use, building coverage, and infrastructure typology of the riverbanks," 2020, doi: 10.1088/1755-1315/447/1/012052.

[15] D. Marwasta and T. D. K. Rahayu, "Spatial distribution of slums and its association with disaster vulnerability in Yogyakarta City," 2020, doi: 10.1051/e3sconf/202020003011.

[16] S. W. Lee, S. J. Hwang, S. B. Lee, H. S. Hwang, and H. C. Sung, "Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics," *Landsc. Urban Plan.*, 2009, doi: 10.1016/j.landurbplan.2009.02.008.

[17] K. Asnake, H. Worku, and M. Argaw, "Assessing the impact of watershed land use on Kebena river water quality in Addis Ababa, Ethiopia," *Environ. Syst. Res.*, 2021, doi: 10.1186/s40068-020-00208-y.

[18] S. C. Azhar, "Land Use and River Water Quality Relationships in the Muda River Basin," *Malaysia. Educ. J. Sci. Math. Technol.*, 2021.

[19] Z. Luo, Q. Shao, Q. Zuo, and Y. Cui, "Impact of land use and

urbanization on river water quality and ecology in a dam dominated basin," *J. Hydrol.*, 2020, doi: 10.1016/j.jhydrol.2020.124655.

[20] L. Wu *et al.*, "Impacts of land use change on river systems for a river network plain," *Water (Switzerland)*, 2018, doi: 10.3390/w10050609.

[21] S. P. Saraswati, M. V. Ardion, Y. H. Widodo, and S. Hadisusanto, "Water Quality Index Performance for River Pollution Control Based on Better Ecological Point of View (A Case Study in Code, Winongo, Gadjah Wong Streams)," *J. Civ. Eng. Forum*, 2019, doi: 10.22146/jcef.41165.

[22] Y. Wijayanti, S. Harliantoro, O. Setyandito, and K. Budihardjo, "Water quality index for river water assessment of Serang River Basin and Kulon Progo Regency, Yogyakarta," 2021, doi: 10.1088/1755-1315/729/1/012031.

[23] K. Y. DLH, "Dokumen Informasi Kinerja Pengelolaan Lingkungan Hidup Daerah Kota Yogyakarta Tahun 2019," 2019.

[24] K. Y. DLH, "Laporan Kinerja Instansi Pemerintah Dinas Lingkungan Hidup 2021," 2021.

[25] R. Mahabir, A. Crooks, A. Croitoru, and P. Agouris, "The study of slums as social and physical constructs: Challenges and emerging research opportunities," *Reg. Stud. Reg. Sci.*, 2016, doi: 10.1080/21681376.2016.1229130.

[26] A. Patel, N. Koizumi, and A. Crooks, "Measuring slum severity in Mumbai and Kolkata: A household-based approach," *Habitat Int.*, 2014, doi: 10.1016/j.habitatint.2013.09.002.

[27] K. Y. BPS, "Badan Pusat Statistik Kota Yogyakarta," 2022.

[28] F. Bostanmaneshrad, S. Partani, R. Noori, H. P. Nachtnebel, R. Berndtsson, and J. F. Adamowski, "Relationship between water quality and macro-scale parameters (land use, erosion, geology, and population density) in the Siminehrood River Basin," *Sci. Total Environ.*, 2018, doi: 10.1016/j.scitotenv.2018.05.244.

[29] S. M. Kerstens, I. Leusbrock, and G. Zeeman, "Feasibility analysis of wastewater and solid waste systems for application in Indonesia," *Sci. Total Environ.*, 2015, doi: 10.1016/j.scitotenv.2015.05.077.

[30] S. Sudarmadji, "Changes of Groundwater Quality in the Sorrounding Pollution Sources Due to Earthquake Dissaster," *Forum Geogr.*, 2016, doi: 10.23917/forgeo.v20i2.1813.

[31] E. Sriyono, Sardi, and N. C. Kresnanto, "Assessment of the quality of well water in the spatial terraces of river code in Yogyakarta Indonesia," 2019, doi: 10.1088/1757-899X/650/1/012057.

[32] Indrastuti, S. Kazama, and S. Takizawa, "Evaluation of microbial contamination of groundwater under different topographic conditions and household water treatment systems in special region of Yogyakarta province, Indonesia," *Water (Switzerland)*, 2021, doi: 10.3390/w13121673.

[33] A. Yulistyorini *et al.*, "Performance of anaerobic baffled reactor for decentralized waste water treatment in urban Malang, Indonesia," *Processes*, 2019, doi: 10.3390/pr7040184.

[34] Muryanto, Suntoro, T. Gunawan, P. Setyono, A. Nurkholis, and N. F. Wijayanti, "Distribution of nitrate household waste and groundwater flow direction around Code River, Yogyakarta, Indonesia," *Indones. J. Geogr.*, 2019, doi: 10.22146/ijg.43420.

[35] M. H. Ward *et al*., "Workgroup report: Drinking-water nitrate and health - Recent findings and research needs," *Environ. Health Perspect.*, 2005, doi: 10.1289/ehp.8043.

[36] M. H. Ward *et al*., "Drinking water nitrate and human health: An updated review," *International Journal of Environmental Research and Public Health*. 2018, doi: 10.3390/ijerph15071557.

[37] Q. Zhang, H. Qian, P. Xu, W. Li, W. Feng, and R. Liu, "Effect of hydrogeological conditions on groundwater nitrate pollution and human health risk assessment of nitrate in Jiaokou Irrigation District," *Journal of Cleaner Production*, 2021, doi: 10.1016/j.jclepro.2021.126783.

[38] D. Suwarno, A. Löhr, C. Kroeze, and B. Widianarko, "Past and future trends in nutrient export by 19 rivers to the coastal waters of Indonesia," *Journal of Integrative Environmental Sciences.*, 2013, doi: 10.1080/1943815X.2013.772902.